16

A STUDY OF SOME COASTAL DUNE LAKES IN WESTERN VICTORIA

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ABSTRACT: To the west of Portland, there are several small lakes lying on coastal calcareous dunes. Their water is clear, hard, alkaline and dominated by Na+ and Cl^- ions. Zooplankton in most is sparse or dominated by the copepods *Gladioferens spinosus* and *Sulcanus conflictus*. The benthos of two lakes includes the polychaete *Boccardia limnicola*. The presence of these three species, together with geomorphological evidence, suggests a marine origin for nearly all lakes. The main exception, Swan Lake, contains the copepod *Calamoecia tasmanica* and is similar to dune lakes on the east coast of Australia.

INTRODUCTION

There are a number of coastal lagoons of fresh water in the south and east of Australia. East of Bass Strait these lie on siliceous sands and have characteristic features (pH $<$ 5, TDS $<$ 100 ppm, *Calamoecia tasmanica* the typical planktonic crustacean) as described by Bayly (1964). To the west of Bass Strait, coastal sands are calcareous (Bird 1967) and hence lakes of different character might be expected. On King Island, where there is a mixture of the two sand types (Jennings 1957), dune lakes are heterogenous but essentially similar to the siliceous dune type (Brand 1967).

The only coastal freshwater lakes of any note in south-west Victoria lie to the west of Portland, between Bridgewater and Nelson. Bayly (1963) has recorded the copepods *Sulcanus conflictus* and *Gladioferens spinosus* from the Bridgewater Lakes; the presence of the latter species is significant for it indicates the lake had a past marine contact (Timms 1973). Hence, the Bridgewater Lakes, and possibly the others near them are basically different from those on the siliceous dunes which developed independently of direct marine contact.

This paper explores this possibility by analysing the modes of origin, water chemistry, some other physico-chemical features, and the major animal communities, especially the zooplankton, of these coastal lagoons.

THE LAKES

Between the Glenelg River mouth (near Nelson) and Cape Bridgewater there are 10 lakes and several swamps (Fig. 1). Most lie in a swale between a low, outer Pleistocene dune, incompletely covered with recent dunes, and a higher mass of Pleistocene dune limestone. The outer dunes are composed of calcareous sand of high (90 - 100%) lime content (Boutakoff 1963). Lake Bong Bong, part of the Glenelg estuary, and Long Swamp, lie in the western end of the swale. To the south-east of Bong Bong the swale is divided by recent dunes into compartments in which Sheepwash Lagoon and Cains Hut Swamp lie. The south-eastern extremity of the swale contains the four Bridgewater Lakes (the largest is here termed the Main Bridgewater Lake).

The centre region and much of the southern part of the long swale is largely obscured by advancing Recent dunes. Thirteen kilometres south-east of Cains Hut Swamp, Malseed Lake lies in a hollow, closed in on three sides by advancing dunes. Swan Lake occupies the lower portion of a valley cut into a scarp of consolidated Pleistocene dunes by Johnstons Creek and is bounded at the seaward end by Recent dunes. In addition to these lakes there is a small unnamed lagoon (here termed Lagoon No. 4) in a depression in the inner consolidated dunes.

The seven lakes studied are small and shallow (Appendix 1). Only Bong Bong and the Main Bridgewater Lake are of any size (*c*. 60 and 40 ha) and depth (7 and 9 m respectively). Not surprisingly much of the lake bottoms are weeded, except for isolated areas on Bong Bong, Main Bridgewater and Swan Lakes. All lakes are no more than 10 m as l, probably much less. Water levels are variable (Appendix 1), particularly in Swan

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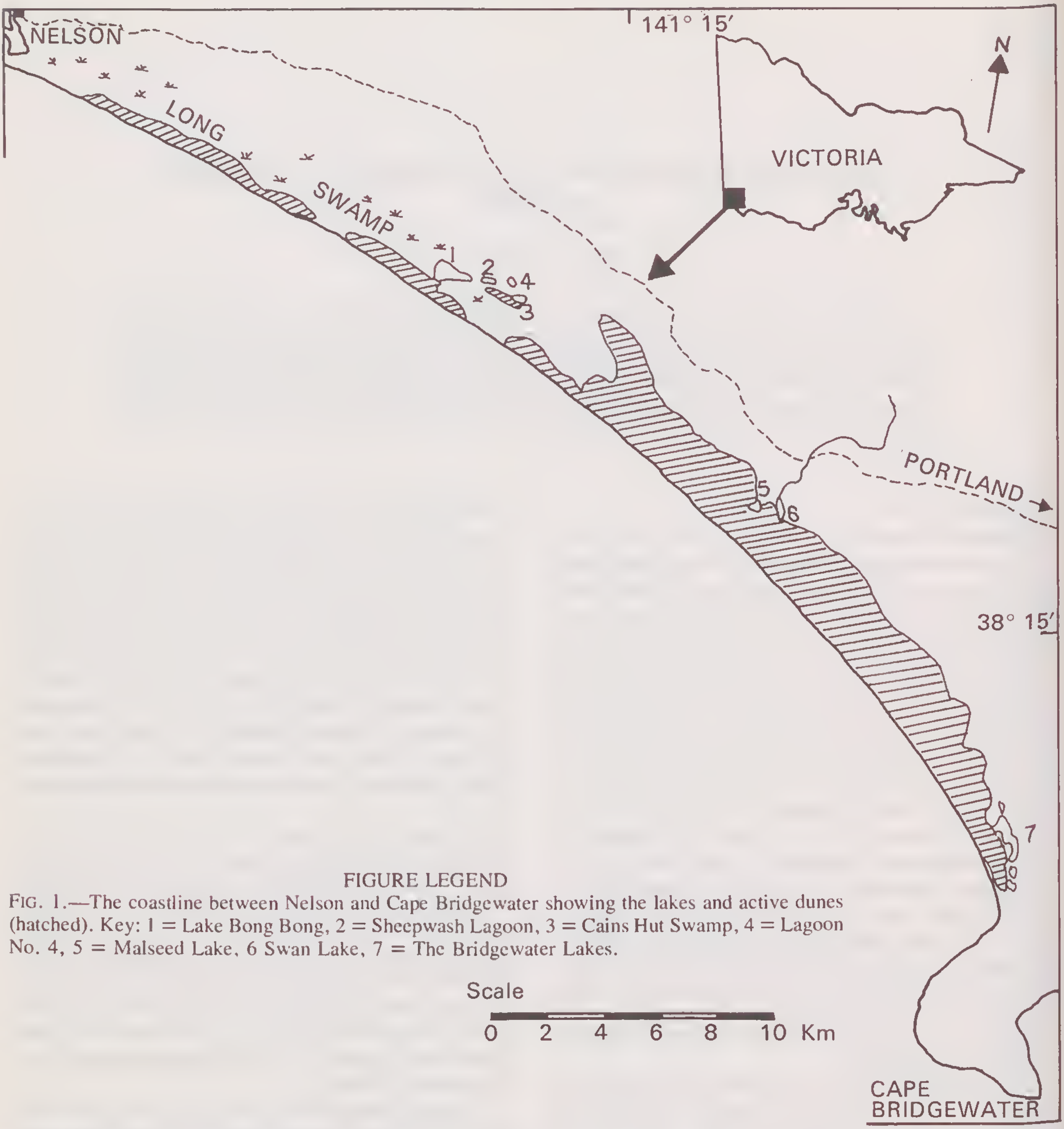

FIGURE LEGEND

FIG. 1.—The coastline between Nelson and Cape Bridgewater showing the lakes and active dunes (hatched). Key: 1 = Lake Bong Bong, 2 = Sheepwash Lagoon, 3 = Cains Hut Swamp, 4 = Lagoon No. 4, 5 = Malseed Lake, 6 Swan Lake, 7 = The Bridgewater Lakes.

Lake, the only lake with an inflow and outflow. The latter has breached the dune barrier but flows only when lake level is exceptionally high. In wet years the Bridgewater Lakes merge to form a continuous body of water.

METHODS

The Lakes were visited on three occasions: in March and November, 1970 and in August 1972.

Light penetration was determined by Secchi disc and water colour was measured against methyl orange standards and expressed in Pt units on the basis of 0.01 mg/l methyl orange being equivalent by 2.8 Pt units (see Hutchinson 1957 p. 413).

Total Dissolved Solids (hereafter TDS) were determined by evaporation at 105°C and pH with a Metrohm portable pH meter. Water samples, collected in November 1970, were analysed for sodium, potassium, calcium, magnesium, chloride, bicarbonate, and sulphate according to the methods reported by Timms (1973).

Limnetic zooplankton was collected by oblique tows with a conical net of mesh size 159 μm from the deepest part of each lake. In addition to daytime collections, night samples were taken in Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and Lagoon No. 4. A Birge cone net of mesh size 159 μm, and brass cone mesh size 2.5 mm was used to sample microinvertebrates in littoral weedbeds. In Swan Lake macroinvertebrates were collected by hand from rocks along the shoreline. Benthos was collected with a Birge-Ekman grab of 200 cm² gape in Bong Bong (9 samples), Swan (3 samples) and Main Bridgewater Lake (6 samples).

TABLE 1

SOME PHYSICOCHEMICAL FEATURES OF THE LAKES

Lake	Mean Secchi disc transparency (cm)*	Water colour in Pt units	Mean TDS (ppm)*	Mean pH*
Bong Bong	445⁺	8	340	8.2
Sheepwash	212⁺	11	363	8.0
Cains Hut	324⁺	14	482	8.1
Lagoon No. 4	68⁺	24	357	7.6
Malseed	-	8	415	8.5
Swan	154	56	363	7.8
Bridgewater	507	8	629	8.5

⁺bottom visible
*for range of values measured, see Appendix 1

RESULTS

(a) Some physico-chemical features

Water in each lake, except Swan is transparent (Table 1) so that the bottom is visible everywhere in some, and in most places in others. In Swan Lake, water is light humic brown and relatively opaque.

The mean TDS values for the series range from 340 to 629 ppm (Table 1). The concentrations of major ions in the lakes are presented in Table 2. Cationic dominance orders are Na⟩Ca⟩Mg⟩K in all except the Bridgewater group where the order is Na⟩Mg⟩Ca⟩K. For anions the common order of dominance is $Cl \rangle HC0_3 \rangle S0_4$ but in Lagoon No. 4 it is $HC0_3 \rangle Cl \rangle S0_4$ and in Swan Lake $Cl \rangle S0_4 \rangle HC0_3$.

Water is distinctly alkaline in each lake, the means ranging from 7.6 to 8.5 (Table 1). Lowest values were recorded in November and August (Appendix 1), following abundant rainfall and presumed acidic inflows (Timms 1973). Changes were most marked in Swan Lake.

(b) Some biological features

Zooplankton is both sparse and of low diversity (Table 3) with nine species represented and an average momentary species richness of 1.7 per lake. There is little uniformity in species composition: Lakes Bong Bong and Bridgewater share two species; there are some species common to Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and Lagoon No. 4, while Swan Lake's fauna is the most divergent with 4 out of 6 species peculiar to it (Table 3). The record of *Boeckella nyoraensis* in Swan Lake is the first since its description in 1912 from Nyora, near Westernport.

There is a distinct difference between daytime and night-time collections from Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and Lagoon No. 4. No plankton could be caught in the latter three by day while at night small numbers representing two species per lake (see Table 3) were captured. In Bong Bong *Sulcanus conflictus*, *Mesocyclops leuckarti*, and *Daphnia lumholtzi* were usually present by day while at night large numbers of *Gladioferens spinosus* joined them. This species probably behaves similarly in the Main Bridgewater Lake but no nightime collections were taken to prove it.

Thirty-five species of littoral crustaceans were collected (Table 3). Most are restricted to one or a few lakes, so that species lists for individual lakes are much shorter (8-13 species). The fauna of Swan Lake is the most divergent with 35% of species not found elsewhere in the series (cf. values of 12-20% for the other lakes). Most species in the series are known from a few sites elsewhere, or are widely distributed in southern Australia. (D. Morton, personal communication; Smirnov & Timms, unpublished data).

TABLE 2

CONCENTRATIONS OF MAJOR IONS (m-equiv/l) IN THE SEVEN LAKES

Lake	Na^+	K^+	Ca^{++}	Mg^{++}	Sum of cations	Sum of anions	Cl^-	HCO_3^-	$SO_4^=$
Bong Bong	2.91	0.08	1.99	0.91	5.89	5.88	3.18	2.35	0.35
Sheepwash	2.43	0.04	2.67	0.73	5.87	5.85	2.78	2.65	0.42
Cains Hut	3.91	0.08	1.95	1.05	6.99	6.89	4.10	2.12	0.67
Lagoon No. 4	2.04	0.03	2.94	0.64	5.65	5.79	2.31	3.08	0.40
Malseed	3.48	0.04	1.76	1.17	6.45	6.56	3.80	2.23	0.53
Swan	2.30	0.05	1.31	0.62	4.28	4.31	2.65	0.29	1.37
Bridgewater (west)	6.67	0.17	1.67	2.46	10.97	11.08	6.17	4.54	0.37
Bridgewater (main)	5.87	0.10	1.31	2.03	9.31	9.27	5.80	3.01	0.46
Bridgewater (near east)	7.20	0.14	1.44	2.27	11.05	11.08	7.07	3.37	0.64
Bridgewater (far east)	9.02	0.20	1.48	2.72	13.42	13.32	9.66	2.83	0.83

TABLE 3

LIMNETIC AND LITTORAL CRUSTACEA OF THE LAKES

TAXON	LAKES
LIMNETIC SPECIES	
Cladocera	
Oaphnia lumholtzi Sars	1, 6
Eubosmina meridionalis (Sars)	S
Alona rectangula Sars	3
Copepoda	
Boeckella symmetrica Sars	S
Boeckella nyoraensis Searle	S
Calamoecia tasmanica (Smith)	S
Gladioferens spinosus Henry	1, 2, 3
Sulcanus conflictus Nicholls	1, 6
Acanthocyclops australis (Sars)	S
Mesocyclops leuckarti (Claus)	1, 2, 4, S
Paracyclops fimbriatus (Fischer)	S
LITTORAL SPECIES	
Ostracoda	
Candonocypris assimilis Sars	2
Cypretta viridis King	2
Cypridopsis sp.	3
cypridid "Bridgewater species"	4, 6
Gomphocythere australica Hussainy	2
Mytilocypris mytiloides (Brady)	1, 2, 4
Cladocera	
Ceriodaphnia sp.	S
Simocephalus elizabethae (King)	S, 6
Echinisca pectinata Smirnov	6
Neothrix armata Gurney	S
Streblocercus serricaudatus (Fischer)	4
Alona davidi Richard	S
Alona rectangula Sars	4
Alonella excisa (Fischer)	1, 3
Biapertura kendallensis (Henry)	S
Biapertura rigidicaudis Smirnov	4, S, 6
Biapertura setigera (Brehm)	S, 6
Camptocercus australis Sars	2, 3, S
Chydorus eurynotus Sars	S
Chydorus sphaericus (Muller)	1, 2, S, 6
Graptoleberis testinaria (Fischer)	S, 6
Oxyurella tenuicaudis Sars	1, 2, 3
Pleuroxus aduncus (Jurine)	1, 2, 3
Copepoda	
Bœckella nyoraensis Searle	S
Gladioferens spinosus Henry	1, 6
Ectocyclops phaleratus (Koch)	2, 3, 4
Eucyclops euacanthus (Sars)	1, 4, 6
Eucyclops serratulus (Fischer)	1
Macrocyclops albidus (Jurine)	1, 2
Microcyclops varicans (Sars)	1, 2, 3, 4
Paracyclops fimbriatus (Fischer)	3, S
Attheyella (Chappuisiella) australica (Sars)	2, 6
Attheyella (Delachauxiella) sp.	6
Malacostraca	
Austrochiltonia subtenuis Sayce)	1, 6

Key to lakes: 1 = L. Bong Bong, 2 = Sheepwash Lagoon, 3 = Cains Hut Swamp, 4 = Lagoon No. 4, S = Swan Lake
6 = Main Bridgewater Lake.

Rock substrates occur in limited areas of Swan Lake; on 18 August 1972 they harboured ten species of macroinvertebrates of which the mayfly *Atalophlebia* cf. *australis* was the most common. Other species were the odonate *Hemicordulia tau* Selys, the corixid *Agraptocorixa eurynome* Kirk., the naucorid *Naucorix congrex* Stal., the dytiscids *Antiporus femoralis* Boh., *Lancetes lanceolatus* Clark, *Platynectes* nr *decempunctatus* and an unidentified species, the hydrophilid *Limnoxenus zelandicus* Brown, and the snail *Phyastra cf. gibbosa*.

Few benthic species were collected from Bong Bong (7 species) and Bridgewater (9 species) while none were found in Swan Lake. The polychaete *Boccardia limnicola* Blake and Woodwick, a tubificid *Tubifex tubifex tubifex*, the crab *Halicarcinus lacustris* (Chilton), the amphipod *Paracorphium* cf. *excavatum*, and the chironomid *Cryptochironomus* sp. occurred in both lakes, while the amphipods *Paracalliope* cf. *fluviatilis* and '*Gammarus*' sp. were also collected from Bong Bong, and the chironomids *Procladius villosimanus* Kieffer, *Chironomus oppositus* Walker and *Tanytarsus* sp., and an unidentified psychomyiid trichopteran from the Main Bridgewater Lake. The polychaete, crab and amphipods were most common at shallow stations while the oligochaete and chironomids dominated at greater depths.

DISCUSSION

The Nelson-Bridgewater Lakes owe their origin to sea level changes and coastal dune formation during the Quaternary. Most lie in a long swale between calcareous Pleistocene dunes which in late Pleistocene-Early Recent times were invaded by the sea (Boutakoff 1963). As the sea retreated a series of relictual sea lagoons remained, some to the present day.

The continued presence of these and the formation of others has been made possible by (a) an impervious clay seal and/or buried fossil soils formed in wetter periods of the Pleistocene climatic cycle and (b) by water percolating through the inland dunes by karst processes and surfacing in the interdune trough (Boutakoff 1963).

Since there are marine relictual species in Lake Bong Bong and the Main Bridgewater Lake (see later), it is suggested that these lakes have remained intact since their origin, sea water being gradually replaced by fresh water. The same history probably applies to Sheepwash Lagoon and Cains Hut Swamp. Swan and Malseed Lakes lack a direct marine origin and exist because a Recent dune has blocked a valley and a swamp respectively. Locality No. 4 lies isolated from the swale in a depression of the inner Pleistocene dunes. It has possibly been enlarged by karst processes.

Some of the physiochemical features measured are atypical of lakes in coastal dune regions. Transparencies and TDS values are relatively high and the concentrations of all ions, particularly Ca, Mg and HCO_3, much higher than are usual in dune lakes on siliceous sands (Bayly 1964, Timms 1973). The latter condition is due to the calcareous environment, but despite this, Na and Cl ions dominate in all lakes, save one, indicating the importance of the aerial supply of ions.

The most notable feature of the fauna of the lakes is the presence of three species with marine affinities: *Boccardia limnicola*, *Gladioferens spinosus*, and *Sulcanus conflictus*. *Boccardia limnicola* is the only freshwater species in the family Spionidae (Blake & Woodwick 1976); its other known occurrence is in Lake Barracoota, a marine relictual lake (Timms 1973). *Gladioferens spinosus* is an estuarine species capable of living in closed freshwaters (Bayly 1963), but it can reach them only via water (Timms 1973). The presence of *Sulcanus conflictus*, another estuarine copepod (Bayly 1963), is the only occurrence known for closed freshwater lakes. It is suggested it reached such lakes via past estuarine contact.

Based on a similar mode of origin, Lake Bong Bong, Sheepwash Lagoon, Cains Hut Swamp and the Bridgewater Lakes form a group of homogenous lakes — the Bridgewater series — which contrast with lakes on siliceous dunes in eastern Australia.

The two groups differ in their genesis, water chemistry and fauna:

(i) The marine relictual origin of the Bridgewater series contrasts with that of siliceous dune lakes, which have never had oceanic contact (Bayly & Williams 1973). Further the calcareous dune series lack the typical accumulation of organic matter, induration of the base to form a seal, and perched nature of most of the siliceous dune lakes.

(ii) While water in both lake series is dominated by Na and Cl ions, the presence of large amounts of Ca, Mg and HCO_3 in the Bridgewater series contrasts with their virtual absence in the siliceous dune lakes (Bayly 1964). In addition, water in the former is alkaline and hard, whereas in the latter it is acid and soft (Bayly 1964).

(iii) *Calamoecia tasmanica*, the characteristic siliceous dune lake zooplankter (Bayly 1964), is absent in the Bridgewater series; instead widespread zooplankters (*Daphnia lumholtzi*, *Mesocyclops leuckarti*) or those characteristic of estuarine waters (*Gladioferens spinosus*, *Sulcanus conflictus*) are present. The presence of a polychaete and a crab further characterizes the Bridgewater Lakes.

It is clear that there is little relationship between lakes in the two series, despite their common position in coastal dunes. Some of the distinctive features of the Bridgewater series are associated with a calcareous environment, but it is their marine ancestry which is outstanding.

Swan Lake does not share the characteristics of the Bridgewater series, neither are many of its features typical of siliceous dune lakes. Of the latter the humic water and the presence of *Calamoecia tasmanica* are significant. These, together with other features, such as genesis by valley or depression damming, hard alkaline water, relatively large amounts of Ca, Mg and HCO_3 ions, and the presence of *Boeckella symmetrica*, *Mesocyclops leuckarti*, various other cyclopoids and *Eubosmina* sp. are typical of dune lakes on King Island (Brand 1967). This suggests that lakes developing on calcareous dunes independently of oceanic contact (e.g. Swan Lake and those on King Island) are a distinct lake type, but somewhat similar to siliceous dune lakes.

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APPENDIX 1

THE LAKES: DATES OF VISITS, LOCATION, AND PHYSICOCHEMICAL DATA RECORDED ON EACH VISIT

Lake	Dates of visits		Location		Morphometry		Fluctuation of water level between visits (m)	Physicochemical parameters		
	1970	1972	Lat. (S.)	Long. (E.)	Approx area (ha)	Approx max. depth (m)		Secchi disk transparency (cm)	TDS ppm	pH
Lake Bong Bong	30-iii, 17-xi	12-viii	38° 08'	141° 11'	50	7	1	426, 210, 700^{+}	370, 404, 345	8.5, 8.2, 8.0
Sheepwash Lagoon	30-iii, 17-xi	12-viii	38° 08'	141° 11'	5	2.5	0.5	210^{+}, 205^{+}, 220^{+}	354, 407, 328	8.2, 7.9, 8.0
Cains hut Swamp	30-iii, 17-xi	12-viii	38° 08'	141° 12'	8	4.5	0.5	257, 305, 410^{+}	555, 457, 435	8.3, 7.8, 8.1
Lagoon No. 4	17-xi	12-viii	38° 08'	141° 12'	5	1	0.2	70^{+}, 67^{+}	407, 307	7.8, 7.5
Malseed Lake	17-xi	12-viii	38° 13'	141° 17'	18	1	0.5	-------	445, 385	8.4, 8.6
Swan Lake	30-iii, 17-xi	18-viii	38° 13'	141° 17'	12	4	3	120, 255, 88	557, 317, 214	8.2, 7.7, 7.4
Main Bridgewater Lake	30-iii, 18-xi	18-viii	38° 19'	141° 24'	40	9	2	500, 490, 530	636, 728, 522	8.8, 8.4, 8.4

$^{+}$bottom visible